Investigation: Transit Tracks

Students will learn

- what a transit is
- under what conditions a transit may be seen
- how a planet's size and distance from its star affects the behavior of transits
- how to interpret graphs of brightness vs time to deduce information about planet-star systems.

Materials and Preparation

- Clip-on lamp with frosted spherically shaped low wattage (25 W maximum) bulb.
- 4 beads, various sizes (3-12mm) and colors on strings of various lengths (20-100cm).
- Set of 5 graphs "Transit Light Curves" - one set per group of 2-5 students (master on p. 3).
- Blank paper and pencils pens (1 ea/student).
- Account of Jeremiah Horrocks observations of the transit of Venus from http://kepler.nasa.gov/ed/lc
- Optional: light sensor and computer with sensor interface and graphing function. Optional Distance/Size worksheets and Kepler's 3rd Law graph (masters on pp. 5–6).

A. What is a transit?

1. Introduce students to the concept of transits by reading a short account of the first transit observation by Jeremiah Horrocks (http://kepler.nasa.gov/ed/horrocks.html)

2. Demonstrate a transit by positioning the clip-on lamp at a height between standing eye-level and seated eye-level. Swing the largest bead on a string/thread in a circle around the lamp, with the lamp at the center in the plane of the orbit. Tell the class that the light bulb represents a star and the bead a planet; the planet is orbiting its star, like the Earth or Venus orbit the Sun.

   a. With students seated, ask if anyone can see the bead go directly in front of the star. If the lamp is high enough, none of the students will be able to see the bead go directly in front of the star.

   b. Ask students to move to where they can see the bead go directly in front of the star--it's OK to stand or crouch. After a show of hands indicates everyone can see that event, confirm that is what we mean by a transit—an event where one body goes in front of another, like a planet goes in front of a star.

B. How does a planet's size and orbit affect the transit?

To see how planet's diameter and orbit affect transits, orbit the other beads around the light. Make those with shorter strings go in smaller radius orbits with shorter period. Define "period" as the time for one orbit. Ask the students what's different about the planets. They should identify: size, color, period, distance from the star. Ask them if there is any relationship between the planet's period and how far it is from the light. They should notice that the farther it is from the light, the longer the period.

C. Interpreting Transit Graphs

1. Imagine a light sensor. Have students imagine they have a light sensor to measure the brightness of the star (light bulb). Move a large opaque object (e.g. a book or cardboard) in front of the star so that its light is completely blocked for all the students. Ask, "If we plotted a graph of brightness vs time—with brightness measured by our light sensor—and this [book] transited the star for 3 seconds, what would the graph look like?" Have volunteers come up and draw their ideas on the board and discuss with the class. We would expect the graph to look like the one shown in Fig. 1: a drop in brightness to 100% blocked.

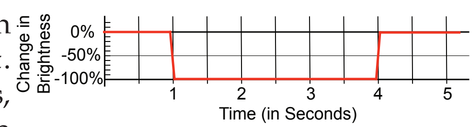


Figure 1. Light curve for a book passing in front of a light.

2. Graph for an orbiting planet. Ask the students, "What would a graph of sensor data look like for the orbiting planet, if we plotted brightness vs time?" Have volunteers draw their ideas on the board, and discuss with class. If their comments do not encompass the idea that the dips in brightness would be very narrow and that their depth would depend on the size of the beads/planets, ask them questions about how wide and deep the dips should be. We would expect the graph to look like the one shown in Fig. 2: horizontal line with dips in brightness to X% blocked.

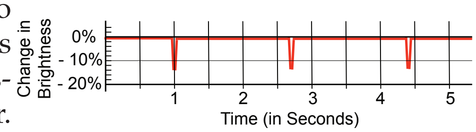


Figure 2. Light curve for a bead orbiting a light.

3. What the graphs can tell us. Explain that with transit data, it's possible to calculate a planet's diameter and distance from its star. Ask, "Why do you think those two properties, planet diameter and distance from star, might be important?"

4. Analyze light curves. Hand out a set of 5 sample graphs of Transit Light Curves to each group of 2-5 students and have them interpret the graphs. Pose these questions: How big is the planet compared with the star? Assuming the star is Sun-like, and that Earth would make at 0.01% drop in brightness of the Sun if it transited, how big is the planet compared with Earth? What is/are the period(s) of the planet(s)? (In Earth years.) How far is the planet from its star? (Use graph of Kepler's 3rd Law) Lead a whole class discussion about the graphs, ultimately aiming at answering the questions.

D. Making Light Curves

1. Students create their own light curves, choosing planet size and orbit radius, and figuring out how to make the period for their graphs.

2. Trade light curves. They then trade graphs with other groups and challenge each other to figure out what kind of planet system they created.

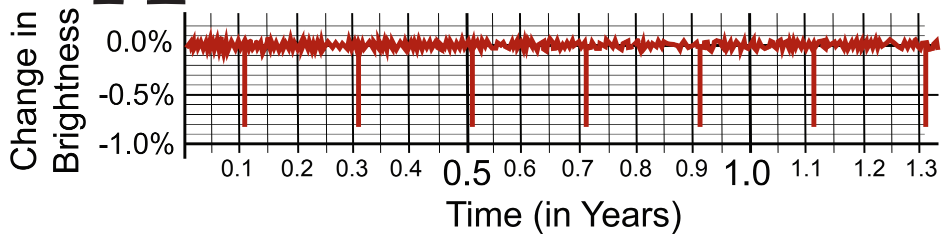
Optional: Collect Real Data

If you have a light sensor, computer with sensor interface, graphing software, and a computer display projector, place the light sensor in the plane of the planet/ bead orbit and aim sensor directly at the light. Collect brightness data and project the computer plot in real time. Let the students comment on what they are observing. Instead of swinging beads, you may use a mechanism, known as an orrery, to model the planets orbiting their star. Instructions for building an orrery from LEGO™ parts may be found on the NASA Kepler Mission website at http://kepler.nasa.gov/ed/lego.html.

Optional Transit Math.

Have the students compute planet size (from transit depth) and distance from its star (from transit period and Kepler's 3rd Law. See write-up for this at http://kepler.nasa.gov/ed/lc

A



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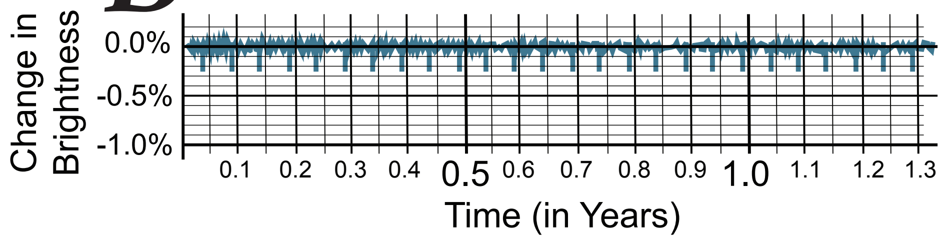

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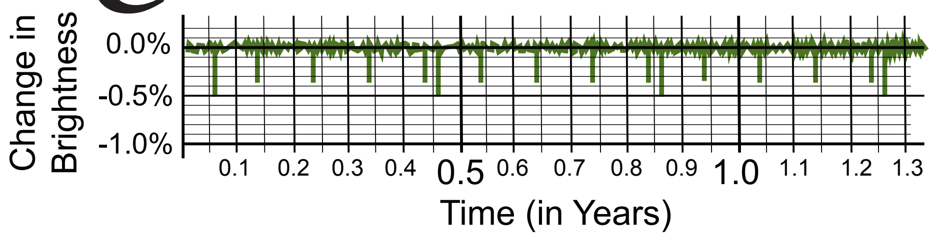

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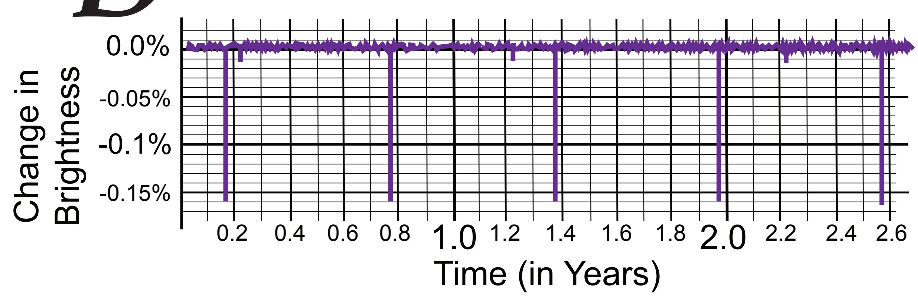

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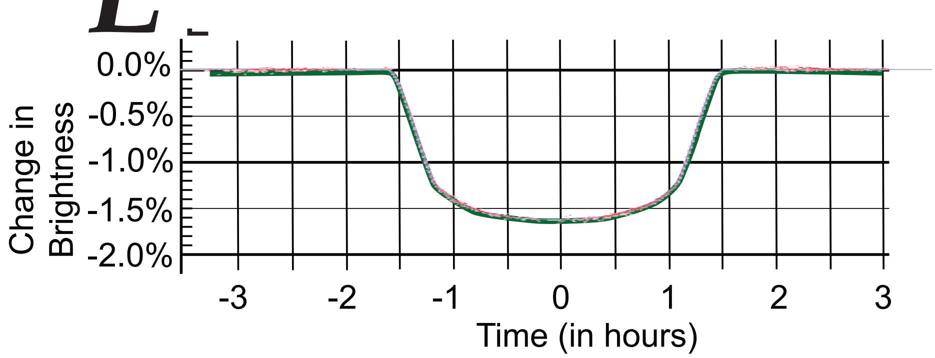
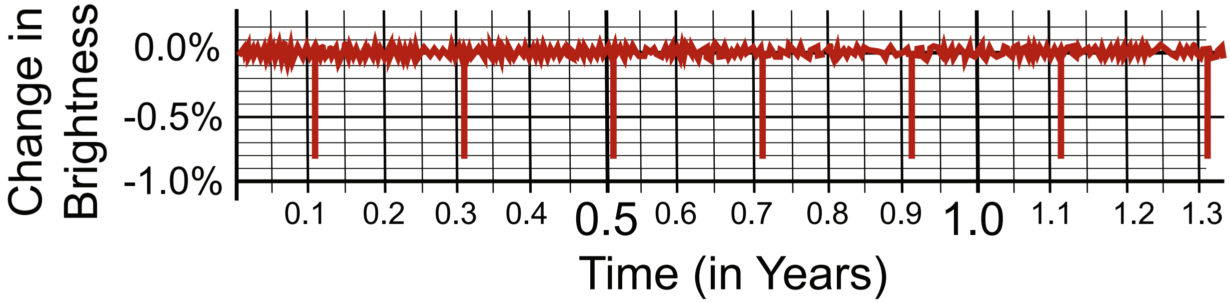


Transit Light Curves

for Tracking Transits Investigation

A



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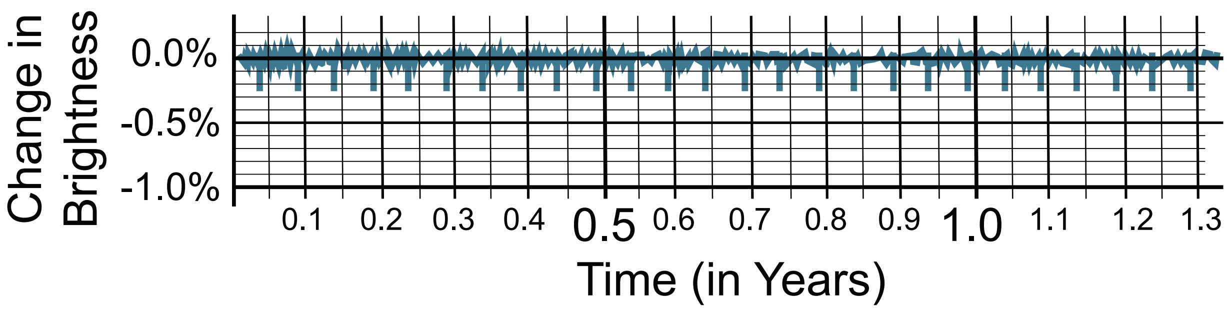

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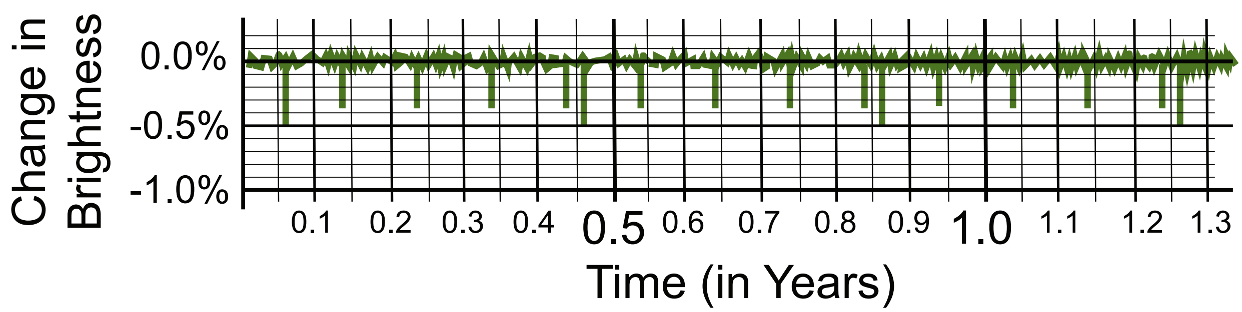

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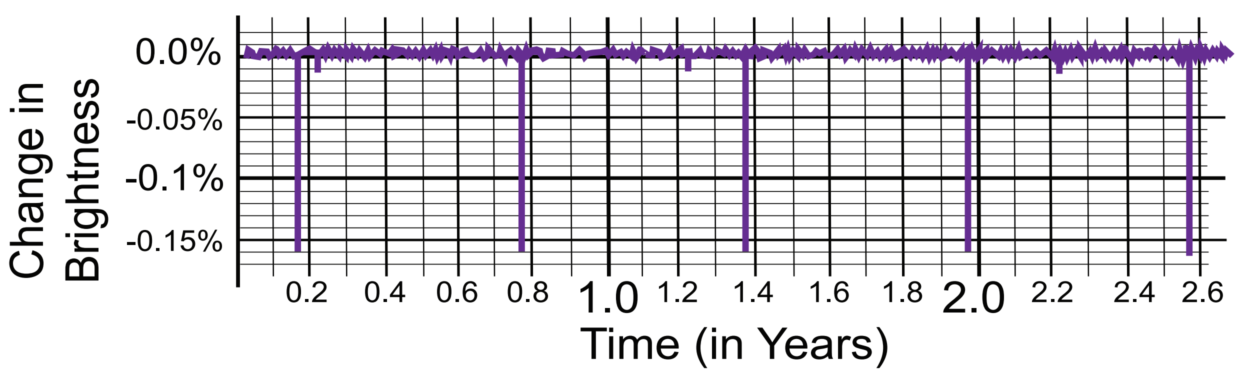

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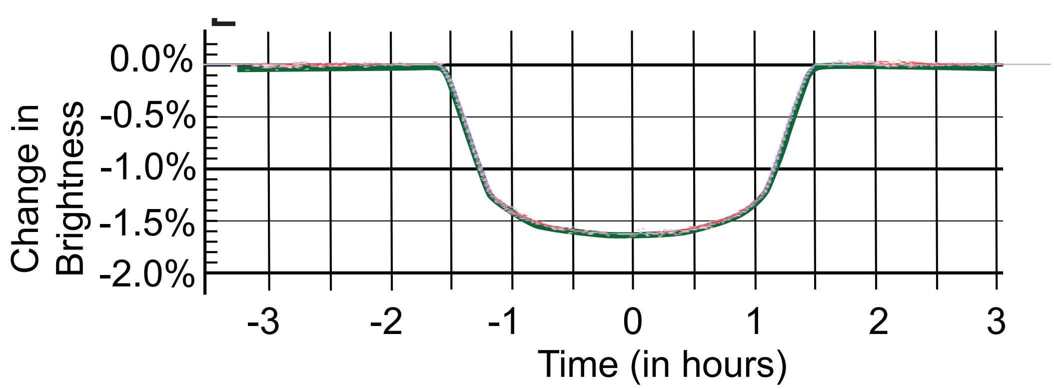


Optional Math for Transit Tracks

To introduce some math in the "Tracking Transits" investigation, have the students compute planet size and distance from its star.

PLANET DISTANCE FROM ITS STAR

The distance of the planet from the star is the radius (R) of its orbit, if the orbit is a circle with the star at the center. In reality, planet orbits are ellipses, but for simplicity, we can imagine the special case ellipse: a circle. Johannes Kepler found that a planet's orbit radius is related to its period (T), the time it takes to orbit. The farther out the planet is, the longer it takes to orbit. The relationship is known as Kepler's 3rd Law. Students can do the Kepler's 3rd law computation in one of two ways:

Method A-Graphical.

Use a graph of Kepler's 3rd Law: Orbital Radius (R) vs Orbital Period (T) on a logarithmic scale (master for photocopy on page 6). Logarithmic scale is needed to make adequate spacing in the inner solar system. Otherwise Mercury, Venus, Earth, and Mars would be so squeezed together, you could not distinguish them easily (see linear graph on page 10).

Method B-Computational.

Use formula for Kepler's 3rd Law: If we are dealing with a Sun-like star and express distance in AU (<u>A</u>stronomical <u>U</u>nit = average distance from Earth to the Sun), then Kepler's 3rd Law is simply:

$$R^3 = T^2 \qquad *$$

or

$$R = \sqrt{T^2}$$

* *Note: There is actually a constant K implied in this equation that sets the units straight:*

R^3/T^2 = K *where* K = 1 $AU^3/Year^2$

Students can use a worksheet to make this computation simple with easy steps. Master for photocopy is on page 6.

It's a good idea to do an example and give some for exercise:

T = 1 yr, 2.83 yr, 5.196 yr, 0.3535 yr
R = 1 AU, 2 AU, 3 AU, 1/2 AU

PLANET SIZE

If we call the percent drop in brightness on a light curve graph Z%, and if the star is about the size of the Sun, then the radius of the planet (r_p) as compared with the radius of Earth (r_e) is

$$r_p = 10\ r_e \times \sqrt{Z}$$

Do an example and the give some examples to students as exercises: Z = 25%, 49%, 9%, 16%, 4%

For Z= 25%, r_p = 50 Earth radii

Note if Z=49%, it's probably not a planet at all, but a companion star in a binary star system.

For more "hot shot" students that get done fast, challenge them to derive the formula using algebra. Have them start with the basic idea that drop in brightness is the ratio of the area of the planet (A_p) to the area of the star (A_s):

$$A_p/A_s \times 100 = Z\%$$

They can use the formula for Area

$$A = \pi r^2$$

Here are the steps:

$$100 \times \pi r_p^2/\pi r_s^2 = Z\%$$

or $r_p = r_s \times \sqrt{(Z/100)} = r_s \times \sqrt{(Z)}/10$

where r_s is the radius of the star.

If the star is about the size of the Sun, then the radius of the star is about 100 times the radius of Earth (r_E) and

$$r_p = 10 r_E \times \sqrt{Z} \quad \text{(QED)}$$

Two ways to take the cube root of a number:

I. Cube Root table on pp 7–9, based on table at http://www.geocities.com/longhairedbastard/appendix3.htm

II. On a calculator that has ln or log function,

1. Enter X,
2. press the "ln" (or "log") key,
3. divide by 3,
4. then press "e^x" (or 10^x) key

And you now have the cube root of X.

Note the "e^x" key may require using the "inv" key on your calculator, depending how your function keys are laid out.

Orbit Distance and Planet Size Worksheet

	Orbit Distance (from Kepler's 3rd Law graph)		Planet Size (using formula)		
Star/ Planet	Period (T in years)	Orbit Distance (in AU)	Brightness Drop - Z (%)	$\sqrt{Z}$	Planet Radius = 10 x $\sqrt{Z}$ (in Earth radii - Earth = 1

Orbit Distance

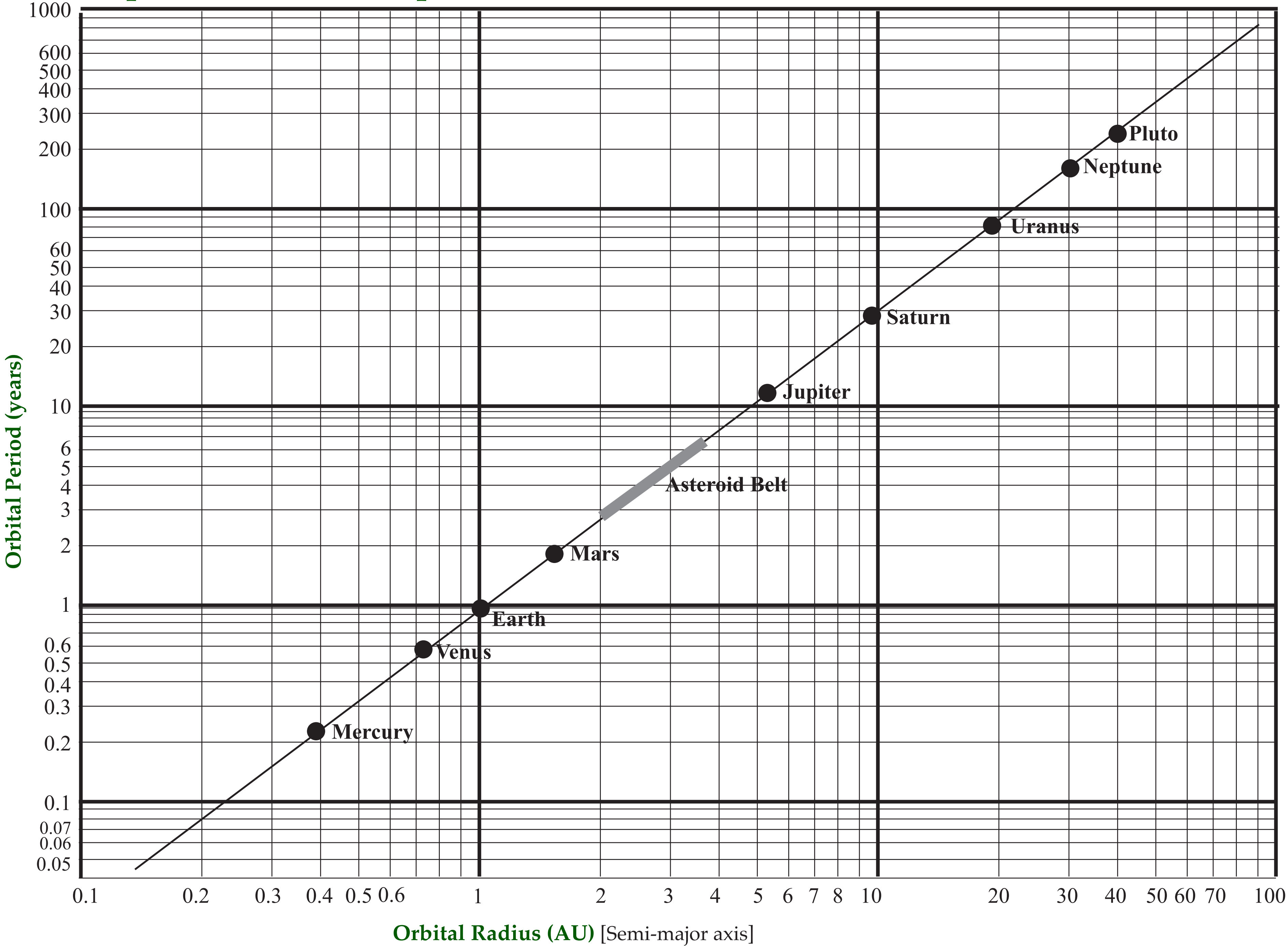
byalternative method: using formula

Star/Planet	Period (T in years)	T^2	Orbit Distance = $\sqrt[3]{T^2}$ (in AU)

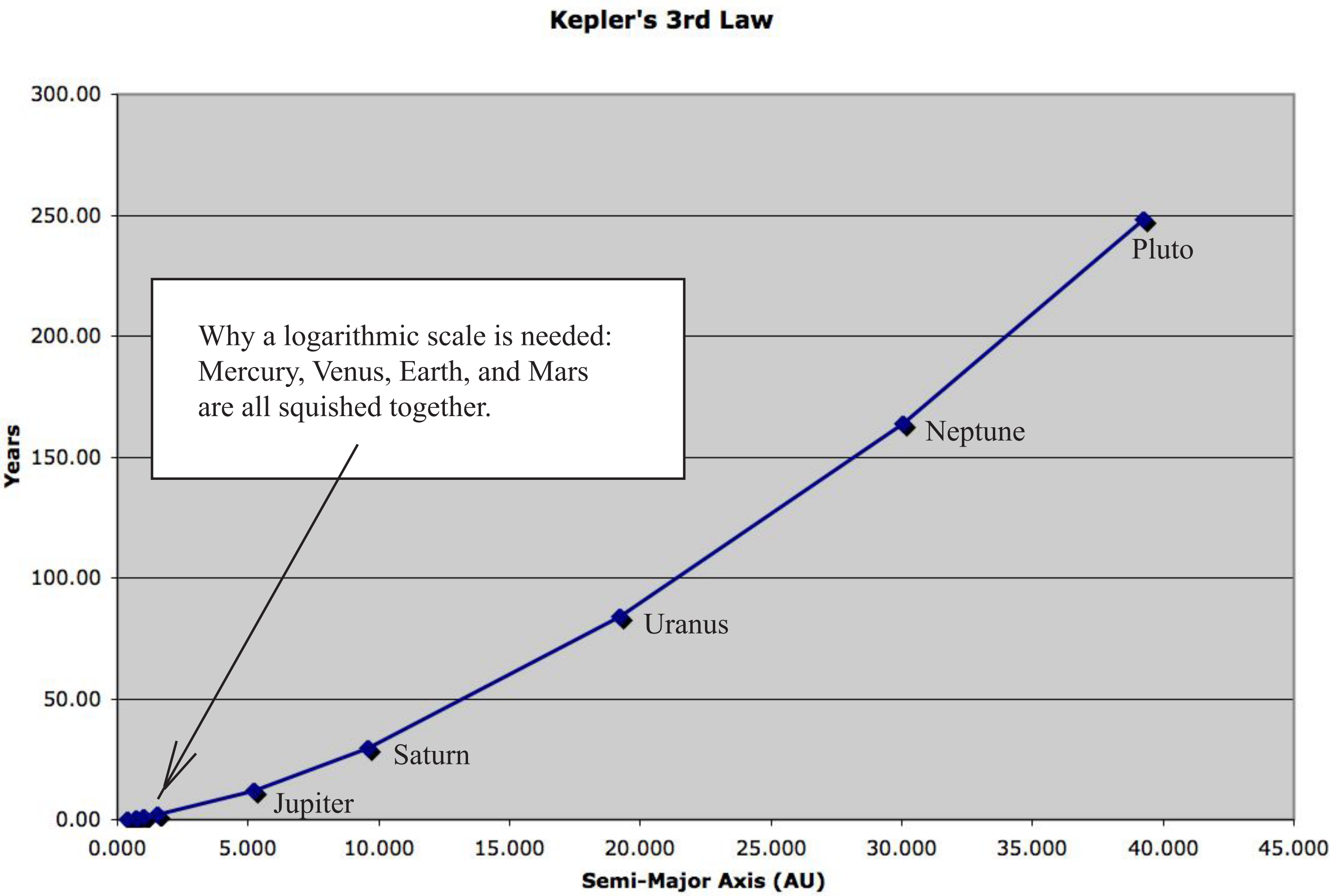
CUBE ROOTS

Number	Cube Root	Number	Cube Root
0.0025	0.136	0.18	0.565
0.0050	0.171	0.2	0.585
0.0075	0.196	0.22	0.604
0.0010	0.100	0.24	0.621
0.0100	0.215	0.26	0.638
0.02	0.271	0.28	0.654
0.03	0.311	0.3	0.669
0.04	0.342	0.32	0.684
0.05	0.368	0.34	0.698
0.06	0.391	0.36	0.711
0.07	0.412	0.38	0.724
0.08	0.431	0.4	0.737
0.09	0.448	0.5	0.794
0.1	0.464	0.6	0.843
0.12	0.493	0.7	0.888
0.14	0.519	0.8	0.928
0.16	0.543	1	1.000

Keplers's 3rd Law Graph



Linear axes


Kepler's 3rd Law
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Years
0.000
5.000
10.000
15.000
20.000
25.000
30.000
35.000
40.000
45.000
Semi-Major Axis (AU)
Why a logarithmic scale is needed:
Mercury, Venus, Earth, and Mars
are all squished together.
Pluto
Neptune
Uranus
Saturn
Jupiter